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Beta titanium alloy, method for the production of a hot-rolled product from an alloy of this type, and uses thereof

Beta titanium alloys with high vanadium contents are distinguished by high strength and also effective toughness or ductility. They are conventionally processed in a hot-forming process to form semi-finished products such as metal sheets, rods, hollow or solid profile members, and wires, from which high-quality, light-weight components are then produced.

The basic principles of the production and characteristics of beta titanium alloys are described in U. Zwicker, *Titan- und Titanlegierungen* ("Titanium and Titanium Alloys"), Springer: Berlin, Heidelberg, New York (1974). In addition to titanium as the matrix metal, beta titanium alloys therefore conventionally contain, as principal alloys elements stabilising the β mixed crystal, V, Nb, Ta, Mo, Fe and Cr, as well as certain contents of Zr, Sn, Al and additives of Si.

A beta titanium alloy and a method for the production of components from this alloy are also known from DD 281 422 A5. In the known alloy, the contents of Cr and V are in total 1.5 to 4.5 mass %, while the content of Cr is limited to less than 2.5 mass %. In addition, the known alloy contains less than 2.0 mass % Fe, 3.8 to 4.8 mass % Al, 1.5 to 4.5 mass % Mo, as well as 1.5 to 2.5 mass % Sn, 2.8 to 4.8 mass % Zr and less than 0.3 mass % Si. According to the known method, a

melt having a composition of this type is cast to form bars, which are then hot-formed, in a process carried out in two stages, to form a component. The component that is obtained is brought into solid solution by means of a heat treatment process, in which its temperature is maintained at 10°C to 40°C below a value designated in DD 281 422 A5 as the "β transus" real value. After this heat treatment process, the part is then kept between 550°C and 650°C for 4 to 12 hours. The parts treated in this manner have a yield point $R_{p0.2}$ of at least 1,100 MPa and tensile strength R_m of at least 1,200 MPa.

Further examples of beta titanium alloys are provided in AT-PS 272 677, EP 0 408 313 B1 and EP 0 600 579 B1. Common to the prior art documented in all of these documents is the endeavour to provide a titanium alloy that may be cast as easily as possible, while at the same time having good mechanical characteristics and being able to be produced cost-effectively.

However, practical experience has shown that the known alloys, both with respect to their strength and with respect to their expansion behaviour, do not satisfactorily meet the requirements set by the processors and users.

The object of the invention was therefore to provide a high-strength beta titanium alloy that has good plastic characteristics prior to curing, for the purposes of effective formability, and high fatigue strength after curing and may be produced cost-effectively. A method by means of which high-strength components may be produced cost-effectively from an alloy of this type is also to be indicated.

With respect to the material, this object is achieved by a beta titanium alloy that contains (in mass %): V: 10 to 17%, Fe: 2 to 5%, Al: 2 to 5%, Mo: 0.1 to 3%, and optionally one or more alloy elements from the group of Sn, Si, Cr, Nb, Zr according to the following proportions: Sn: 0.1 to 3%, Si: 0.1 ≤ 2%, Cr: ≤ 2%, Nb: ≤ 2%, Zr: ≤ 2%, wherein the beta titanium alloy may additionally comprise contents of C and of elements from the group of the lanthanides, and as the remainder Ti and inevitable impurities.

At ambient temperature, a beta titanium alloy having the composition according to the invention easily achieves a yield point $R_{p0.2}$ of at least 1,400 MPa, a tensile strength R_m of at least 1,500 MPa, and a plastic strain $\epsilon_{p0.2}$ of more than 4%. Its density ρ does not exceed 4.8 g/cm^3, so components that are not only extremely strong, but also weight-optimised, may be produced using a beta titanium alloy according to the invention.

This is achieved, firstly, in that the alloy according to the invention comprises significantly higher vanadium contents than those provided in beta titanium alloys in the prior art. As a result of the high V contents, the β phase of the structure is stabilised and the high-temperature strength increased. In an alloy according to the invention, the V content is therefore preferably in the range from 12 to 17 mass %, in particular in the range from 13 to 17 mass %.

Contents of 2 to 5 mass % aluminium stabilise the α phase of the structure and cause effective mixed crystal hardening.

The effect of the iron in the titanium alloy having the composition according to the invention consists in a stabilisation of the β phase of the structure, an increase in

the high-temperature strength and an improvement in the mixed crystal formation.

Molybdenum in contents of 0.1 to 3 mass %, preferably at least 0.5 mass %, is contained in a titanium material according to the invention to stabilise the β phase of the structure and to increase the high-temperature strength.

A beta titanium alloy according to the invention optionally also contains one or more alloy elements from the group of Sn, Si, Cr, Nb, Zr.

The presence of tin has a beneficial effect on the mixed crystal hardening and the high-temperature strength. The Sn contents are therefore preferably in the range from 0.5 to 3 mass %.

In an alloy according to the invention, silicon increases the high-temperature strength and the oxidation resistance.

Chromium may be added to the alloy to stabilise the β phase of the structure and to increase the high-temperature strength.

Adding niobium may also have a beneficial effect on the high-temperature strength and the oxidation resistance of the alloy.

Finally, it may also be advantageous, for improving the mixed crystal formation and the oxidation resistance, to add zirconium to the alloy according to the invention.

In addition to the components of which the effect has been described in detail above, the alloy according to the

invention may contain further components, provided that they do not negatively affect the characteristics achieved according to the invention. These include, in particular, contents of carbon and contents of elements associated with the group of the lanthanides.

Optimal characteristics of the beta titanium alloys according to the invention are achieved if the above-specified limit values are observed to within at least two decimal places.

With respect to the method, the above-specified object is achieved in that the manufacturing of a product produced from a beta titanium alloy involves the following steps:

- melting a beta titanium melt having the composition according to the invention to form a preliminary product in block form,

- hot-forming the preliminary product,

- hot end forming the hot-formed preliminary product to form a hot end product,

- solution annealing the hot end product,

- cold-forming the hot end product to form an end product,

- curing treatment of the end product.

The hot end forming process for the production of strips or metal sheets may be carried out as a hot-rolling process, which may, if necessary, be followed by a coiling process.

The Ti alloy according to the invention may be produced in a particularly cost-effective manner in that the alloy elements V, Fe and Al are added by alloying, in a manner known *per se*, not individually, but rather in the form of a master alloy. Master alloys of this type are commercially available.

The hot end product obtained by means of the method according to the invention after the hot-forming process consists of a single-phase, metastable beta titanium, the transus temperature T_B of which is approximately 788°C. If the hot end product is produced by means of a hot-rolling process, it comprises crystals stretched in the rolling direction and possesses a partially dynamically re-crystallised structure.

The preliminary product in block form, which is processed during the method according to the invention, is obtained by means of re-melting. A Vacuum Arc Re-melt furnace may, in a manner known *per se*, be used for this purpose.

The preliminary products may, for example, be rounded blocks, which are hot-formed during the hot-forming process to form billets or mill bars. Billets of this type are typically square with edge lengths of, for example, 70 mm or round with a diameter of, for example, 60 mm.

The hot end forming process is typically carried out at forming temperatures in the range from 950°C to 1,150°C, in order to achieve an effective reduction of cross-sectional area and a homogenisation of the composition and the structure.

If the hot end forming process is carried out as a hot-rolling process, an advantageous configuration of the method according to the invention provides that the hot end product

is solution annealed after the hot end forming process. The solution annealing process is followed by the cold-forming process. The solution annealing process typically takes place for 30 minutes at 875°C.

To further increase the values of the mechanical characteristics, the hot end product, which may be solution annealed, is annealed in a re-crystallising manner. For holding times of 20 to 40 minutes, the temperatures during this annealing treatment are typically in the range from 775°C to 875°C.

Cold-forming, for example by means of cold-rolling, then takes place. The end product obtained after the cold-forming process has a yield point $R_{p0.2}$ of at least 870 MPa to 900 MPa, a tensile strength R_m of 890 MPa to 944 MPa, and a plastic strain of 14 to 17%.

After the rolled product, which has been annealed in a re-crystallising manner, is then subjected to a curing treatment, the product that is obtained has a yield point $R_{p0.2}$ of at least 1,400 MPa, a yield strength R_m of at least 1,500 MPa, and elongation ϵ_{p1} of at least 4%. For a treatment period of typically 5 hours, the typical temperature of the curing treatment is approximately 480°C. Provided that these time and temperature requirements are adhered to, an optimal characteristic spectrum of the end products produced according to the invention is achieved.

Semi-finished products such as mill bars, metal sheets, rods, profile members or wires, which, owing to their characteristic profile, are ideal as high-strength components, may be produced from a beta titanium alloy having the composition according to the invention. The semi-finished

products may, in particular, be produced cost-effectively by using the method according to the invention.

Beta titanium alloys according to the invention have proven particularly suitable as constructional materials for the production of components used in rail or road vehicles and in air and space travel. Examples of components for this use include axle springs, connecting rods, piston pins, high-strength screws, brake pistons and brake discs.

Beta titanium alloys according to the invention are also particularly suitable, owing to their specific characteristics, for the production of components used in the fields of general mechanical engineering, apparatus engineering, plant engineering, container construction, cryogenics, vehicle construction, or in the field of sport.

It has been found that beta titanium alloys having the composition according to the invention are particularly suitable for the production of components that are used in the temperature range from -196°C to 300°C.

The invention will be described below in greater detail with reference to an embodiment.

Rounded blocks containing (specified in mass %) 15% V, 4% Fe, 3% Al, 1% Mo, 1% Sn and 0.3% Si, the remainder being Ti and inevitable impurities, which were then hot-formed, in a forging process, to form square billets, were melted in a VAR furnace. During alloying of the melt, the alloy components V, Fe and Al were jointly added, in the form of an inexpensive master alloy, to the matrix material Ti.

After the forging process, the billets were hot-rolled, at hot-rolling temperatures in the range from 1,100°C to 950°C, to form wire and were then wound to form coils. After the hot-rolling process, the wire comprised single-phase, metastable β titanium (transus temperature T_{β} of approximately 788°C) with crystallites stretched in the direction of the wire axis and a partially dynamically re-crystallised structure.

Following the coiling process, the wire was solution annealed for 30 minutes at 875°C. Following the solution annealing process, the wire was cold-formed. After the cold-forming process, the wire was annealed in a re-crystallising manner at temperatures between 775°C and 875°C for a holding period in the range from 20 minutes to 40 minutes. The wire annealed in this manner had a yield point $R_{p0.2}$ between 870 MPa and 900 MPa, a tensile strength R_m between 890 MPa and 944 MPa, and elongation A between 14% and 17%. The re-crystallisation annealing process was followed by a curing treatment, in which the wire was maintained for 5 hours at 480°C.

At ambient temperature, the wire thus finished had a yield point $R_{p0.2}$ of more than 1,400 MPa, a tensile strength R_m of more than 1,500 MPa, and elongation A at least in the range from 4% to 5%.